Claims

1. A frequency synchronization apparatus that estimates a frequency error between an input signal from an external source and a reference signal, based on a correlation therebetween, and corrects the input signal so as to cancel out the frequency error, the input signal including a synchronization symbol that is composed of a synchronization waveform that exhibits a predetermined autocorrelation property and is included at least twice in the synchronization symbol, and the reference signal expressing a waveform that is identical to the synchronization waveform, the frequency synchronization apparatus comprising:

a correlation unit operable to successively find correlation vectors between the input signal and the reference signal;

a timing detection unit operable to generate, based on chronological transition in magnitude of the obtained correlation vectors, a synchronization waveform timing signal that indicates a predetermined timing in each cycle of the synchronization waveform;

a first frequency error detection unit operable to find a frequency error between the input signal and the reference signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors, each of

which is obtained with the timing indicated by the synchronization waveform timing signal;

an absolute phase error detection unit operable to find an absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of correlation vectors found with the timing indicated by the synchronization waveform timing signal; and

a first frequency correction unit operable to correct the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the found frequency error and the found absolute phase error.

2. The frequency synchronization apparatus of Claim 1, further comprising:

a frequency error holding unit operable to hold the found frequency error, and, when a new frequency error is subsequently found, update the held frequency error with the new frequency error depending on a difference between the held frequency error and the new frequency error; and

an absolute phase error holding unit operable to hold the found absolute phase error, and, when a new absolute phase error is subsequently found, update the held absolute phase error with the new absolute phase error depending on a difference between the held absolute phase error and the new absolute phase error,

wherein the first frequency correction unit corrects the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the frequency error being held by the frequency error holding unit and the absolute phase error being held by the absolute phase error holding unit.

3. The frequency synchronization apparatus of Claim 1, further comprising:

a second frequency correction unit operable to be supplied with a control signal, and give an output signal from the first frequency correction unit a frequency shift corresponding to the control signal;

an absolute phase error detection unit operable to demodulate an output signal from the second frequency correction unit and successively find symbol points in the demodulated output signal, and detect a phase error between the found symbol points and symbol points able to be found in a modulation method of the output signal; and

a second frequency error detection unit operable to successively output to the second frequency correction unit a control signal for giving an output signal from the first frequency correction unit a frequency shift that cancels out the detected phase error.

4. The frequency synchronization apparatus of Claim 3, further comprising:

a frequency error holding unit operable to hold the found frequency error, and, when a new frequency error is subsequently found, update the held frequency error with the new frequency error depending on a difference between the held frequency error and the new frequency error; and

an absolute phase error holding unit operable to hold the found absolute phase error, and, when a new absolute phase error is subsequently found, update the held absolute phase error with the new absolute phase error depending on a difference between the held absolute phase error and the new absolute phase error,

wherein the first frequency correction unit corrects the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the frequency error being held by the frequency error holding unit and the absolute phase error being held by the absolute phase error holding unit.

5. The frequency synchronization apparatus of Claim 3,

wherein the input signal has been modulated according to a multicarrier modulation method,

the phase error detection unit demodulates an output signal

from the second frequency correction unit and, for each sub-carrier in the demodulated output signal, successively finds symbol points in the sub-carrier and detects phase error between the found symbol points and symbol points able to be obtained in a modulation method of the sub-carrier,

the frequency synchronization apparatus further comprises:

a phase error averaging unit operable to average phase errors detected simultaneously for all or some of the sub-carriers, and

the second frequency detection unit successively outputs to the second frequency correction unit a control signal for giving an output signal from the first frequency correction unit a frequency shift that cancels out the average phase error.

6. The frequency synchronization apparatus of Claim 1, wherein

the input signal includes a data symbol in addition to the synchronization symbol, and

a band of the synchronization symbol is limited so as to fall within an occupied frequency band of the data symbol.

7. The frequency synchronization apparatus of Claim 6, wherein

the synchronization symbol is characterized in that the synchronization waveform is included at least twice with a predetermined time interval therebetween.

8. A frequency synchronization circuit that estimates a frequency error between an input signal from an external source and a reference signal, based on a correlation therebetween, and corrects the input signal so as to cancel out the frequency error, the input signal including a synchronization symbol that is composed of a synchronization waveform that exhibits a predetermined autocorrelation property and is included at least twice in the synchronization symbol, and the reference signal expressing a waveform that is identical to the synchronization waveform, the frequency synchronization circuit comprising:

a correlation circuit operable to successively find correlation vectors between the input signal and the reference signal;

a timing detection circuit operable to generate, based on chronological transition in magnitude of the obtained correlation vectors, a synchronization waveform timing signal that indicates a predetermined timing in each cycle of the synchronization waveform;

a first frequency error detection circuit operable to find a frequency error between the input signal and the reference

signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors, each of which is obtained with the timing indicated by the synchronization waveform timing signal;

an absolute phase error detection circuit operable to find an absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of correlation vectors found with the timing indicated by the synchronization waveform timing signal; and

a first frequency correction circuit operable to correct the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the found frequency error and the found absolute phase error.

9. A one-chip integrated circuit that estimates a frequency error between an input signal from an external source and a reference signal, based on a correlation therebetween, and corrects the input signal so as to cancel out the frequency error, the input signal including a synchronization symbol that is composed of a synchronization waveform that exhibits a predetermined autocorrelation property and is included at least twice in the synchronization symbol, and the reference signal expressing a waveform that is identical to the synchronization waveform, the one-chip integrated circuit comprising:

in input terminal operable to obtain the input signal;

a correlation circuit operable to successively find correlation vectors between the input signal and the reference signal;

a timing detection circuit operable to generate, based on chronological transition in magnitude of the obtained correlation vectors, a synchronization waveform timing signal that indicates a predetermined timing in each cycle of the synchronization waveform;

a first frequency error detection circuit operable to find a frequency error between the input signal and the reference signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors, each of which is obtained with the timing indicated by the synchronization waveform timing signal;

an absolute phase error detection circuit operable to find an absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of correlation vectors found with the timing indicated by the synchronization waveform timing signal;

a first frequency correction circuit operable to correct the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the found frequency error and the found absolute phase error; and

an output terminal operable to output the corrected input signal.

10. A frequency synchronization method that estimates a frequency error between an input signal from an external source and a reference signal, based on a correlation therebetween, and corrects the input signal so as to cancel out the frequency error, the input signal including a synchronization symbol that is composed of a synchronization waveform that exhibits a predetermined autocorrelation property and is included at least twice in the synchronization symbol, and the reference signal expressing a waveform that is identical to the synchronization waveform, the frequency synchronization method comprising:

a correlation step of successively finding correlation vectors between the input signal and the reference signal;

a timing detection step of identifying, based on chronological transition in magnitude of the obtained correlation vectors, each cycle of the synchronization waveform;

a first frequency error detection step of finding a frequency error between the input signal and the reference signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors that are representative of the identified cycles;

an absolute phase error detection step of finding an

absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of correlation vectors that are representative of the identified cycles; and

a first frequency correction step of correcting the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the found frequency error and the found absolute phase error.

11. The frequency synchronization method of Claim 10, further comprising:

a frequency error recording step of recording the found frequency error, and, when a new frequency error is subsequently found, updating the recorded frequency error with the new frequency error depending on a difference between the recorded frequency error and the new frequency error; and

an absolute phase error recording step of recording the found absolute phase error, and, when a new absolute phase error is subsequently found, updating the recorded absolute phase error with the new absolute phase error depending on a difference between the recorded absolute phase error and the new absolute phase error,

wherein the first frequency correction step corrects the input signal by simultaneously giving the input signal a

frequency shift and a phase rotation that cancel out the frequency error recorded in the frequency error holding step and the absolute phase error recorded in the absolute phase error recording step.

12. The frequency synchronization method of Claim 10, further comprising:

a second frequency correction step of being instructed of a frequency shift, and giving a signal obtained in the first frequency correction step the instructed frequency shift;

an absolute phase error detection step of demodulating a signal obtained in the second frequency correction step and successively finding symbol points in the demodulated output signal, and detecting a phase error between the found symbol points and symbol points able to be found in a modulation method of the output signal; and

a second frequency error detection step of successively instructing to the second frequency correction step of a frequency shift that cancels out the detected phase error.

13. The frequency synchronization method of Claim 12, further comprising:

a frequency error recording step of recording the found frequency error, and, when a new frequency error is subsequently

found, updating the recorded frequency error with the new frequency error depending on a difference between the recorded frequency error and the new frequency error; and

an absolute phase error recording step of recording the found absolute phase error, and, when a new absolute phase error is subsequently found, updating the recorded absolute phase error with the new absolute phase error depending on a difference between the recorded absolute phase error and the new absolute phase error,

wherein the first frequency correction step corrects the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the frequency error recorded in the frequency error holding step and the absolute phase error recorded in the absolute phase error recording step.

14. The frequency synchronization method of Claim 12, wherein

the input signal has been modulated according to a multicarrier modulation method,

the phase error detection step demodulates a signal obtained in the second frequency correction step and, for each sub-carrier in the demodulated output signal, successively finds symbol points in the sub-carrier and detects phase error between

the found symbol points and symbol points able to be obtained in a modulation method of the sub-carrier,

the frequency synchronization method further comprises:

a phase error averaging step of averaging phase errors detected simultaneously for all or some of the sub-carriers in the absolute phase error detection step, and

the second frequency detection step successively instructs the second frequency correction step of a frequency shift that cancels out the average phase error.

15. A synchronization symbol generation method, comprising:

a selection step of selecting a numeric sequence that expresses a digital signal and that has a predetermined autocorrelation property;

a synchronization waveform generation step of generating a synchronization waveform by eliminating a high frequency component that is outside a desired band from the digital signal expressed by the numeric sequence whose sampling frequency is treated so as to be half or less of the desired band width; and

a synchronization symbol generation step of generating a synchronization symbol so as to include the synchronization waveform at least twice.

16. The synchronization symbol generation method of Claim 15,

wherein in the synchronization symbol generation step, the synchronization symbol is generated such that a predetermined time interval is placed between each synchronization waveform.

17. A signal transmission method for transmitting a signal that includes a predetermined synchronization symbol and correcting a received signal using a synchronization symbol included in the received signal, comprising:

a selection step of selecting a numeric sequence that expresses a digital signal and that has a predetermined autocorrelation property;

a synchronization waveform generation step of generating a synchronization waveform by eliminating a high frequency component that is outside a desired band from the digital signal expressed by the numeric sequence whose sampling frequency is treated so as to be being half or less of the desired band width;

a synchronization symbol generation step of generating a synchronization symbol so as to include the synchronization waveform at least twice;

a transmission step of transmitting a signal that includes the generated synchronization symbol;

a reception step of receiving the transmitted signal; and

a synchronization step of estimating a frequency error between the received signal and a reference signal that expresses the synchronization waveform, based on a correlation between the received signal and the reference signal, and correcting the received signal so as to cancel out the frequency error.

18. The signal transmission method of Claim 17, wherein in the synchronization symbol generation step, the synchronization symbol is generated such that a predetermined time interval is placed between each synchronization waveform.

19. The signal transmission method of Claim 17, wherein the synchronization step includes:

a correlation sub-step of successively finding correlation vectors between the received signal and the reference signal;

a timing detection sub-step of identifying each cycle of a synchronization waveform included in the received signal, based on a chronological transition in magnitude of the found correlation vectors;

a first frequency error detection sub-step of finding a frequency error between the received signal and the reference signal, based on an average phase difference of chronologically neighboring pairs of correlation vectors that are representative

of each identified cycle; and

a first frequency correction sub-step of correcting the received signal by giving the received signal a frequency shift that cancels out the found frequency error.

20. The signal transmission method of Claim 19,

wherein the synchronization step further includes:

an absolute phase error detection sub-step of finding an absolute phase error between the received signal and the reference signal, based on chronological transition of absolute phase of the correlation vectors that are representative of each identified cycle, and

in the first frequency correction sub-step, the received signal is corrected by simultaneously giving the received signal a frequency shift and phase rotation that cancel out the found frequency error and the found absolute phase error.

AMENDED CLAIMS

[received by the International Bureau on 27 August 2004 (27/08/2004)
Original claim 12 replaced by amended claim 12; Claims 15, 16, 17, 18, 19 and 20 deleted;
Claims 21, 22, 23 added remaining claims unchanged]

frequency shift and a phase rotation that cancel out the frequency error recorded in the frequency error holding step and the absolute phase error recorded in the absolute phase error recording step.

12. (amended) The frequency synchronization method of Claim 10, further comprising:

a second frequency correction step of being instructed of a frequency shift, and giving a signal obtained in the first frequency correction step the instructed frequency shift;

a phase error detection step of demodulating a signal obtained in the second frequency correction step and successively finding symbol points in the demodulated output signal, and detecting a phase error between the found symbol points and symbol points able to be found in a modulation method of the output signal; and

a second frequency error detection step of successively instructing to the second frequency correction step of a frequency shift that cancels out the detected phase error.

13. The frequency synchronization method of Claim 12, further comprising:

a frequency error recording step of recording the found frequency error, and, when a new frequency error is subsequently

the found symbol points and symbol points able to be obtained in a modulation method of the sub-carrier,

the frequency synchronization method further comprises:

a phase error averaging step of averaging phase errors detected simultaneously for all or some of the sub-carriers in the absolute phase error detection step, and

the second frequency detection step successively instructs the second frequency correction step of a frequency shift that cancels out the average phase error.

15. (deleted)

16. (deleted)

17. (deleted)

18. (deleted)

19. (deleted)

20. (deleted)

21. (added) A frequency demodulation method that corrects an input signal from an external source, based on a correlation between the input signal and a reference signal, and demodulates the corrected input signal, the input signal including a synchronization symbol that is composed of a synchronization waveform that exhibits a predetermined autocorrelation property and is included at least twice in the synchronization symbol, and the reference signal expressing a waveform that is identical to the synchronization waveform, the frequency demodulation method comprising:

a frequency synchronization step of finding a frequency error between the input signal and the reference signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors found cyclically between the input signal an the reference signal, finding an absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of the correlation vectors, and correcting the input signal based on the found frequency error and the found absolute phase error; and

a demodulation step of demodulating the corrected input signal, thereby generating a demodulated signal.

22. (added) The demodulation method of Claim 21,

wherein the frequency synchronization step further includes:

a correlation sub-step of successively finding correlation vectors between the input signal and the reference signal;

a timing detection sub-step of identifying, based on chronological transition in magnitude of the obtained correlation vectors, each cycle of the synchronization waveform;

a first frequency error detection sub-step of finding a frequency error between the input signal and the reference signal, based on an average phase difference between each pair of chronologically neighboring correlation vectors that are representative of the identified cycles;

an absolute phase error detection sub-step of finding an absolute phase error between the input signal and the reference signal, based on chronological transition of absolute phase of correlation vectors that are representative of the identified cycles; and

a first frequency correction sub-step of correcting the input signal by simultaneously giving the input signal a frequency shift and a phase rotation that cancel out the found frequency error and the found absolute phase error.

23. (added) The frequency synchronization method of Claim 22,

wherein the synchronization step further includes:

a second frequency correction sub-step of being instructed of a frequency shift, and giving a signal obtained in the first frequency correction step the instructed frequency shift;

a phase error detection sub-step of demodulating a signal obtained in the second frequency correction step and successively finding symbol points in the demodulated output signal, and detecting a phase error between the found symbol points and symbol points able to be found in a modulation method of the output signal; and

a second frequency error detection sub-step of successively instructing to the second frequency correction step of a frequency shift that cancels out the detected phase error.